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The reproduction of negative film by telecine

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THE REPRODUCTION OF NEGATIVE FILM BY TELECINE

F.A. Griffiths

Summary

The technique of reproducing negative colour film in a telecine is discussed, and the essential features of the signal processing are described.

The suitability of flying-spot and camera-tube telecines for this purpose is also compared, particularly with reference to the achievable signal-to-noise ratios.

Issued under the authority of

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(PH-101)

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1. Introduction

An appreciable improvement in picture quality may be obtained by directly scanning colour negative film in a telecine. The most important improvements which can result from the elimination of the positive print are an improved luminance transfer characteristic, together with improved colour accuracy and sharpness. These benefits result almost entirely from the elimination of an additional film process which is less than perfect. A further advantage is a reduction of the visibility of flare introduced by the telecine as a result of the low gain necessary in dark areas of the original scene.

This report discusses the required signal processing, methods of control and the means by which these can be realised. Consideration is also given to the signal-to-noise ratios which can be achieved in both flying-spot and camera-tube telecine machines. This is an important factor in the use of negative colour film in a telecine owing to the severe loss of light caused by the coloured mask which is used in most types of negative film.

2. The negative film-telecine process

For a fixed duration of exposure, the relationship between scene brightness (E) and transmission of light through the negative (T) is given by

$$T \alpha E^{-\gamma_n} \qquad (1)$$

where γ_n is the gamma of the negative film.

It is assumed that the telecine is required to produce a normal television signal with the relationship

$$V \alpha E^{1/\gamma_{tv}} \qquad (2)$$

where V = telecine output voltage
γ_{tv} = television display tube gamma

From Equations (1) and (2) the telecine gamma correction required may be found, and is given by:

$$V \alpha T^{\frac{-1}{\gamma_n \gamma_{tv}}}$$

Substituting typical values for γ_n and γ_{tv} we have

$$V \alpha T^{\frac{-1}{0{\cdot}6 \times 2{\cdot}8}}$$

Therefore $V \alpha T^{-0{\cdot}6}$.

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This gamma characteristic may be achieved by the use of logarithmic, inverting and exponential amplifiers in cascade. Its effect is to produce high amplification in regions of scene white and low amplification in shadow regions. For the television gamma corrector to produce a standard level output signal from a linear photocell signal of equal peak magnitude, the required gain at a level corresponding to white in the scene would be in the region of 19 dB. On the other hand, at a level corresponding to 1% white level in the scene, an attenuation of approximately 19 dB would be necessary.

The result of this non-linear amplification is that noise appears in the picture in the highlights while the shadow areas are very noise-free.

3. Signal-to-noise ratio calculations

A calculation was made with the aid of a computer and a mathematical model (see Appendix Table 1) to investigate the requirements for non-linear amplification in the telecine and to assess the resulting overall noise performance. A wide range of film characteristics was considered, together with telecines of both flying-spot and lead-oxide camera-tube types. It should be noted that, in a flying-spot scanner, the random fluctuation noise level varies in proportion to the square root of the photomultiplier signal. In a camera-tube telecine the noise is produced by the head amplifier and is constant in level, being independent of the video signal magnitude.

It was assumed that both types of telecine were fully corrected for the appropriate losses, and produced linear outputs which were of equal unweighted signal-to-noise ratio under open-gate conditions. The film was assumed to have a gamma lying in the range between $-0{\cdot}1$ and $-1{\cdot}0$, and to have recorded upon it a scene contrast of 100 : 1. Some account was also taken of possible variations of the minimum film density (D_{min}) corresponding to 1% of white level in the scene. A range of D_{min} from zero to 0·35 was included in the calculations; this consideration is of importance only in the case of a flying-spot telecine since the intensity of the light source of a camera-tube telecine may be adjusted to compensate for variations in minimum density.

From the results shown in Table 1 of the Appendix, which refer to a maskless (or black and white) negative, it will be seen that the best signal-to-noise ratio is obtained for a flying-spot telecine, when the film has a gamma in the region of $-0{\cdot}5$; for a lead-oxide camera-tube telecine the optimum gamma lies in the region of $-0{\cdot}2$. Practical negative colour films in use at present have gammas in the range $-0{\cdot}5$ to $-0{\cdot}65$.

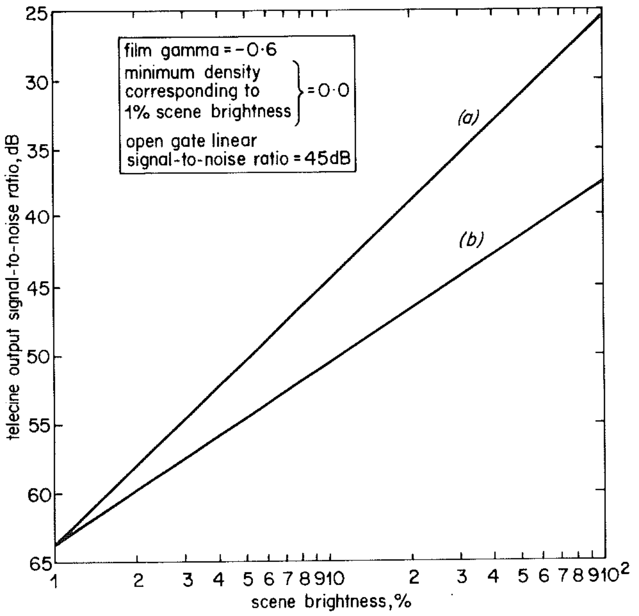

Fig. 1 - Variation of signal-to-noise ratio of telecine output with brightness of scene

(*a*) Lead oxide camera-tube telecine (unmasked film)
(*b*) Flying-spot telecine (unmasked film)

The random fluctuation noise is greatest in the high-lights of the final picture and is at its lowest amplitude in the low-lights. Fig. 1 shows how the noise level varies in the telecine output signal over the range of scene brightness, It is assumed in Fig. 1 that the two types of telecine have equal signal-to-noise ratios (prior to gamma correction) of 45 dB under open-gate conditions, that the film has a gamma of −0·6 and that 1% scene brightness was recorded at zero negative density.

4. Use of masked negative

The orange-coloured mask in the conventional colour negative causes substantial loss of green and blue light passing through the film. The signal-to-noise ratios at the outputs of the photocells of a flying-spot telecine suffer reductions of the order of 5 dB in the case of the green channel and 9 dB in the blue. However, the camera-tube telecine need not have its performance impaired as the colour and intensity of the illuminant may be changed to provide compensation.

In practice a 16 mm flying-spot telecine provides linear open-gate photocell signals with signal-to-r.m.s. noise ratios in the region of 45 dB after afterglow and aperture correction. Measurements on linear signals from an open-gate lead-oxide camera-tube telecine, operating at 300 nA peak signal current and using the necessary aperture correction, gave a signal-to-r.m.s. noise ratio of 42 dB.*

The final achieved signal-to-noise ratios for the two types of telecine may be found by the addition of the noise measurements in the manner shown below.

It should be realised, however, that variations in the final signal-to-noise ratios occur in practice due to the effects of masking and the compensation for exposure errors in the film, but it is found that provided the linear aperture corrected signal from a 16 mm flying-spot telecine under open-gate conditions has a signal-to-noise ratio in the region of 45 dB, then the pictures produced have an acceptable signal-to-noise ratio. At this level the noise is just perceptible in a still picture; with the telecine running the visibility of film grain predominates.

5. Luminance transfer characteristic

The luminance range which may be accurately recorded on negative film and reproduced by a suitable telecine is greater than that obtained from positive or reversal film and

	Flying Spot			Lead Oxide Camera		
	R	G	B	R	G	B
Linear signal, open-gate signal-to-noise ratio (dB)	45	45	45	42	42	42
Deduction for the effect the orange mask (F/S only) (dB)	−0	−5	−9	0	0	0
Deduction for D_{min} of the film (dB)	−3	−3	−3	0	0	0
Improvement of signal-to-noise ratio at a linear signal level of 4% (which corresponds to white in the scene assuming a film of $\gamma = -0{\cdot}6$) (dB)	+12	+12	+12	0	0	0
Degradation of signal-to-noise ratio due to white stretch of the gamma corrector (overall unity gamma reproduction system) (dB)	−19	−19	−19	−19	−19	−19
Total giving the final signal-to-noise ratio of the telecine output signals at white level (dB)	35	30	26	23	23	23

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* This camera-tube telecine employed head amplifiers providing, with 300 nA signal currents, signal-to-r.m.s. noise ratios of 49 dB before aperture correction.

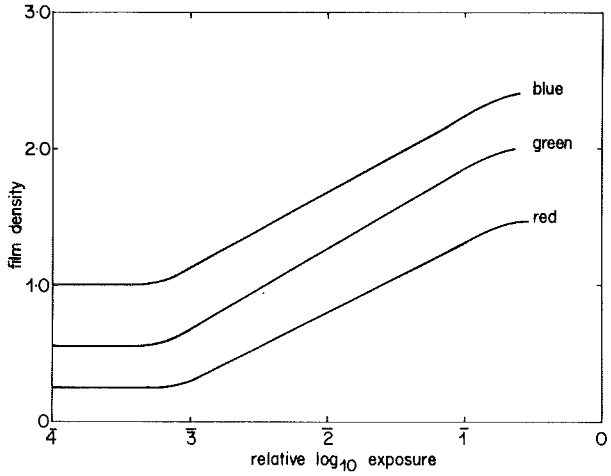

Fig. 2 - Transfer characteristic of a typical colour negative film

indeed is also greater, in principle, than that presently obtained from a television camera. Fig. 2 shows the characteristic of a typical negative film stock and it can be seen that a scene contrast of 100 : 1 may be recorded on the straight part of the characteristic.

Due to the low gamma of negative film stocks a scene contrast of 100 : 1 is reduced to a value between ten- and twenty-to-one in the film. This low gamma recording gives the advantage to a negative-working telecine that the optical flare normally encountered in the reproduction of positive film is made much less visible since the telecine has a low gain in the shadow areas of the picture. The high gain in high brightness areas will also be applied to optical flare but even so it is less noticeable.

The signals from the photocells, proportional to film transmission, require gamma correction in order to present a standard television signal at the telecine output and it has been shown previously that the telecine gamma corrector must produce a signal V where

$$V \propto T^{\frac{-1}{\gamma_n \gamma_{tv}}}$$

if distortion of the reproduced brightness scale is to be avoided. The characteristic of the telecine gamma corrector required, assuming a film gamma of −0·6 and a television display gamma of 2·8, is shown in Fig. 3, and as already stated, at white level the gain is in the region of 19 dB whilst near black, at a relative scene brightness of 1%, the gain of the gamma corrector is −19 dB.*

The required gamma correction is easily obtained using logarithmic and exponential amplifiers in cascade. The signal from each photocell is passed through the logarithmic amplifier, inverted, and then adjusted in level before passing to the exponential amplifier.

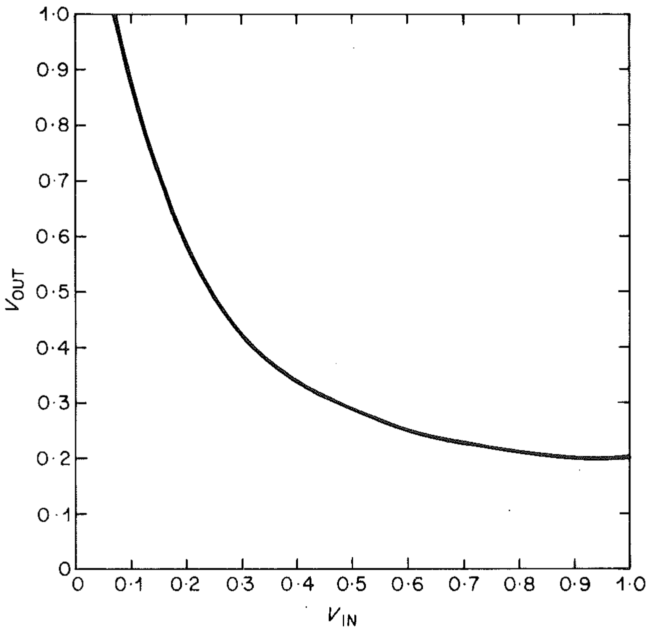

Fig. 3 - Telecine gamma corrector characteristic for negative film gamma of −0·6 and display gamma of +2·8

In practice the limited range of logarithmic and exponential amplifiers may make it necessary for the input to the exponential amplifier to be varied slightly in order to approximate to the desired overall gamma. The final result, however, will be found to be very close to the required power law. Fig. 4 shows results of measuring effective scene brightness (the scene being a wide-range grey-scale which was photographed using a typical colour negative stock) and plotting it against telecine output voltage. This illustrates one of the important features of using negative film in a telecine since it shows that the scene brightness range has been recorded on the film and converted to electrical signals without significant distortion.

6. Colour reproduction

As the luminance range of the combined negative film and associated telecine system is substantially undistorted over a wide contrast range, the differences between the red, green and blue signals are also undistorted over a wide range. The errors in the colour reproduction chain are substantially reduced to those due to imperfect colour analysis of the scene by the film, and those due to limitations of the display phosphors. Some approximate compensation may be provided for the analysis errors which reduces these colour errors to quite a low value (of the order of 4 j.n.d.).

In order to achieve this colour accuracy, however, the telecine must employ electronic masking. The calculation of the matrix to ensure colour fidelity is reported elsewhere[1] but, when using negative film, some small but important complications arise.

A typical colour negative film employs a total of five dyes. The method of calculating masking matrices is based

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* These figures are calculated assuming unity gamma for the overall film and television reproduction system.

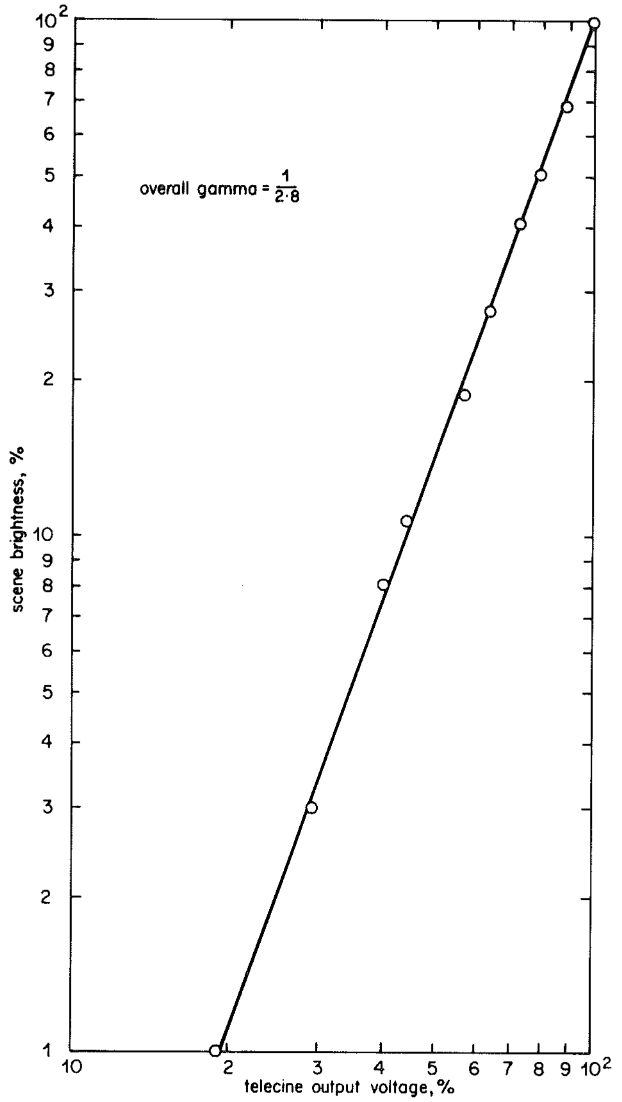

Fig. 4 - Measured transfer characteristic of negative film and telecine system

on there being three dyes in the film. The effects of the two extra masking dyes in the negative film have to be combined with those of the three remaining dyes to produce one set of three equivalent dyes.[2]

With one type of negative film it was possible to carry out chemical processing of the image without activating the orange-coloured dyes. This gave improved signal-to-noise performance in the final television picture for reasons already mentioned, but problems were encountered with this film since the slopes of the transfer characteristics of the three effective dye layers were dissimilar. Any such characteristics must be taken into account in the calculation of electronic masking in order that compensation to ensure 'grey scale tracking' can be made correctly.

7. Resolution and grain

By the removal of the positive print film from the television system the resolution losses due to the film printing process are also removed. This may result in up to 9 dB better resolution at 5 MHz.

However, due to the form of gamma correction used for negative film, grain appears differently distributed throughout the grey scale, as compared with its appearance using positive film. It is most visible in the highlights where, using conventional positive film, there is usually little grain visible due to the 'white crushing' of the print film. The grain is also rendered more visible when using negative directly in a telecine as a result of the improved resolution. The basic grain-to-picture ratio is, however, determined in the negative film and can only be modified by a subsequent printing process, where the loss of resolution can give a less grainy but less sharp picture.

8. Control of telecine signals

In film printing, considerable use is made of grading; that is to say the exposure of the print film is modified in terms of colour balance and brightness in order to provide a print which is relatively consistent and of acceptable quality.

Some of the reasons for the colour and brightness adjustments are obvious; for example, the colour temperature of the scene illumination can vary or the camera operator may not expose the film with a suitable colour-correcting filter in front of the camera lens. The errors due to high gamma in the print film which can distort the colour reproduction of the picture, and the acquisition of colour cast errors due to tolerances in the chemical processing are other reasons for the grading process.

When using negative film directly in telecine it has been found that less colour correction is required. The colour processing of the negative film remains within quite close limits, even with films whose processing was carried out at widely differing times. Corrections are required for colour balance errors due to changes in colour of the scene illuminant and also to compensate for incorrect exposure in the camera. These corrections can be made while reviewing the film in a telecine and may be repeated in future runs of the film by punching the relevant information on to paper tape. The film may then be replayed under the control of the paper tape (in a similar manner to the operation of some film printers) with the colour balance changes being introduced during the field suppression period prior to a change of scene, thereby ensuring the correct reproduction of the whole of a film sequence.[3]

Control of the telecine to compensate for exposure errors may be achieved by adding constants (i.e. additional 'lift' signals) to the logarithmic signals in the telecine processing channel.

If E represents the light which originally exposed one layer of the film, then the photocell signal (T) derived from scanning the processed negative will be related to it by $T \alpha E^{-\gamma_n}$, where γ_n is the gamma of the film. The logarithmic signal in the telecine is log T, thus

$$\log T = -\gamma_n \log E$$

If a constant $-\gamma_n \log K$ is added to the logarithmic signal then it becomes

$$-\gamma_n \log K + \log T = -\gamma_n \log K - \gamma_n \log E$$

$$= -\gamma_n \log KE$$

The signal will therefore become identical with that which would have been obtained if the original exposure of the film had been changed by a factor K.

In practical terms this means that if the gain is decreased, parts of the signal previously acted upon by the white clipper in the telecine such as very bright sky, may be reduced until an undistorted picture of the highlights is presented. This action may result in some shadow detail being lost since a linear overall transfer characteristic is aimed for and probably a contrast range of only some 100 : 1 will be reproduced by the display system. If the gain is increased, then the highlights may be clipped but shadow detail will be visible down to the point where the film is not exposed.

Differences in colour balance due to variations in the illumination of the scene or the effects of incorrect filters used with the camera may now be offset by differential adjustment of the lifts applied to the log R, log G and log B signals.

It has been found in practice that the negative film-television system will handle a slightly greater contrast than that resulting from exposures calculated according to the speed rating of the film and so 'over exposure' of up to one stop can be used with advantage to record more of the scene contrast, with a small improvement in picture quality.

Where a film has been severely under-exposed, adjustment of the gain to bring the highlights to a reasonable signal level may result in the under-exposed parts of the picture being reproduced as a clearly visible grey area. This is an undesirable effect and may be partially compensated by using the conventional 'sit' control. This provides a more pleasing result, although the picture will clearly not contain shadow information which was not recorded on the film.

9. Conclusions

The flying-spot scanner is preferable to the camera-tube type when using negative film. The picture quality obtained is superior to that obtained from positive-print film in respect of contrast range, luminance transfer characteristic, colour reproduction and sharpness. The grading of the film is effective and many of the spurious colour casts encountered in positive films do not occur.

10. References

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Appendix

Derivation of equations used in gamma and noise performance calculations.

Let T = transmission of negative film
E_s = original scene brightness
γ_n = gamma of negative film equivalent dyes
E_p = picture tube brightness
V_c = photocell/lead-oxide camera-tube output
V_T = telecine output
γ_{tv} = picture tube gamma
N = r.m.s. noise on telecine output
G = telecine gamma corrector small signal gain

The picture tube output required is assumed to be proportional to the original scene brightness, i.e.

$$E_p \propto E_s$$

The telecine gamma correction must therefore compensate for the power law characteristics of the picture tube and the film. These are, respectively:

$$E_p \propto V_T^{\gamma_{tv}}$$

and

$$T \propto E_s^{-\gamma_n}$$

Photocells and lead-oxide camera-tubes have linear amplitude responses, i.e.

$$V_c \propto T$$

The transfer function of the telecine gamma corrector is found by substitution:

$$V_T \propto V_c^{-1/\gamma_n\gamma_{tv}}$$

The exponent of the gamma corrector must therefore be $-1/\gamma_n\gamma_{tv}$

The small signal gain of the gamma corrector is found by differentiation of the transfer function

$$G = \frac{dV_T}{dV_c} \alpha - \frac{1}{\gamma_n \gamma_{tv}} V_c^{-\left(1 + \frac{1}{\gamma_n \gamma_{tv}}\right)}$$

The noise output from a lead-oxide camera-tube is independent of the signal amplitude. Therefore, after gamma correction, the noise output will be:

$$N \alpha \frac{1}{\gamma_n \gamma_{tv}} V_c^{-\left(1 + \frac{1}{\gamma_n \gamma_{tv}}\right)}$$

or

$$\frac{1}{\gamma_n \gamma_{tv}} T^{-\left(1 + \frac{1}{\gamma_n \gamma_{tv}}\right)}$$

The noise output from a photocell in a flying-spot telecine is proportional to the square root of the photocell signal current. Therefore the noise output after gamma correction is given by:

$$N \alpha \sqrt{T} \times \frac{1}{\gamma_n \gamma_{tv}} T^{-\left(1 + \frac{1}{\gamma_n \gamma_{tv}}\right)}$$

or

$$\frac{1}{\gamma_n \gamma_{tv}} T^{-\left(\frac{1}{2} + \frac{1}{\gamma_n \gamma_{tv}}\right)}$$

TABLE 1

Comparison of Signal-to-Noise Ratios at White Level Obtainable at Telecine Output

D_{min} = 0	γ_n									
	−0·1	−0·2	−0·3	−0·4	−0·5	−0·6	−0·7	−0·8	−0·9	−1·0
Telecine gain at scene white level (dB)	15·1	13·0	13·6	15·0	17·1	19·5	22·2	25·0	28·0	31·1
Flying spot telecine output S/N ratio (dB)	31·9	36·0	37·5	38·0	37·9	37·5	36·9	36·0	35·0	33·9
Lead oxide telecine output S/N ratio (dB)	29·9	32·0	31·4	30·0	27·9	25·5	22·8	20·0	17·0	13·9
D_{min} = 0·25										
Telecine gain at scene white level (dB)	25·0	14·1	18·3	19·1	20·8	23·0	25·4	28·1	31·0	34·0
Flying spot telecine output S/N ratio (dB)	23·1	31·0	33·8	35·0	35·3	35·1	34·7	34·0	33·1	32·1
D_{min} = 0·35										
Telecine gain at scene white level (dB)	29·0	21·5	20·2	20·8	22·3	24·3	26·8	29·4	32·2	35·2
Flying spot telecine output S/N ratio (dB)	19·6	29·0	32·3	33·8	34·2	34·2	33·8	33·1	32·3	31·3

Linear signals from the telecines under open-gate conditions are assumed to have a signal-to-noise ratio of 45 dB and linear signal gain set to produce full signal amplitude under open-gate conditions.

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